THE UNIVERSITY OF TEXAS

Bureau of Economic Geology and Technology

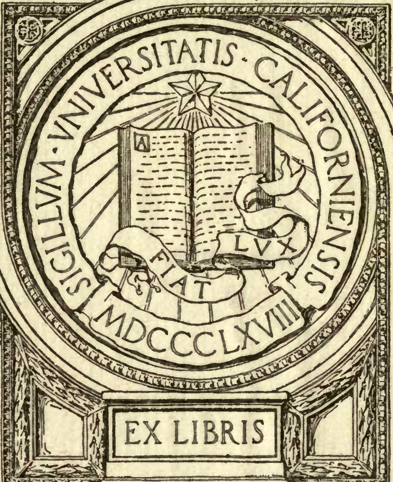
HANDBOOK SERIES NO. 1

AIDS TO IDENTIFICATION OF GEOLOGICAL FORMATIONS

BY

J. A. UDDEN

Published by
The University of Texas
Austin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INTRODUCTION

By long experience many drillers learn to distinguish, generally quite correctly, the three principal classes of sediments in which most of their work is done, such as shale or clay, sandstone and limestone. The most experienced drillers in any locality have, also, expert knowledge of what we may call the "key rocks" of the field in which they work. They know the rocks that determine the depth at which casing is to be set, or the depth at which the tests for oil or gas must be made. This knowledge of rocks is mostly taught from mouth to mouth, by the head driller to his helpers, entirely without any other guidance than the limited experience of each driller. No aid, so far as I know, has ever been prepared by geologists to help drillers in procuring the information both are eagerly seeking.

With the extension of drilling operations to regions of widely different geological formations and conditions, it has become a matter of some urgency that drillers' logs be made with greater accuracy and uniformity than before. The only way to encourage improvement in this direction is to place in the hands of the men who make the "logs," what aid they need. By the use of a few very simple devices, available to all, great improvements in results can be attained without the least loss of time. The present paper is an attempt to present some information, in compact form, that will aid practical and intelligent men to correctly identify materials explored in drilling for oil, gas, or water. It will be found that much of the information here set forth consists of elementary methods and facts drawn from mineralogy and geology. Most drillers are eager to acquire all knowledge they can in these sciences. They have exceptional opportunities in their occupation to return to the geological profession manyfold any little help that can be offered them of the kind here attempted.

MINERALS AND ROCKS

Minerals, when pure, have a more or less constant chemical composition, and with some exceptions they have definite crystalline form. In these respects they differ from rock which may or may not be constant in its chemical composition. By rock we mean any considerable quantity or large body of material which has been brought together into a deposit by some natural process. A mass of ice resulting from the accumulation of snow, is a rock. Salt or calcareous mud precipitated from the waters of the sea and laid down in beds, forms rock. Sand and gravel are rock. When indurated, or hardened, we call these two latter deposits sandstone and conglomerate, respectively. Many rocks consist of mixtures of different kinds of minerals. Many sandstones are mixtures of grains of quartz sand and scales of mica, and many limestones are mixtures of calcite and dolomite.

Minerals are classified according to their chemical composition, while rocks are classified according to the processes by which they have been formed, or the manner in which the materials of which they consist have been brought together.

MINERALS

The number of minerals which occur in sufficient frequency to be of interest in formations that are extensively drilled are quite few. Though more than a thousand different mineral species are known, less than a score are commonly found in the formations which are encountered by drillers in this state. These may be enumerated and classified as follows:

Siliceous minerals:
- Quartz.
- Mica.
- Feldspar.
- Hornblende.
- Serpentine and Chlorite.
- Augite and Pyroxene.
- Glauconite.

Calcareous, lime-bearing, minerals:
- Calcite.
- Dolomite.
- Gypsum and Anhydrite.

Iron-bearing minerals:
- Pyrite and Marcasite.
- Hematite and Limonite.
- Siderite, or clay-iron-stone.

Sodium chloride:
- Salt.

Carbon compounds:
- Asphalt.
- Coal.
- Lignite.

Barium compound:
- Barite.

If these minerals are classified on the basis of the acid elements entering into their composition they arrange themselves in the following groups:

Oxides:
- Quartz.
- Hematite.
- Limonite.

Sulphides:
- Pyrite.
- Marcasite.

Chloride:
- Salt.

Silicates:
- Mica.
- Hornblende.

Feldspar.
Pyroxene.
Serpentine.
Glauconite.

Carbonates:
Calcite.
Dolomite.
Siderite.

Sulphates:
Gypsum.
Anhydrite.
Barite.

Hydrocarbons:
Asphalt.
Coal.
Lignite.

QUARTZ

Quartz is the oxide of an element called silicon. It is the most common of all minerals and occurs in many varities, such as rock crystal, which is its purest but not its most common form; chert and flint; agate; jasper; chalcedony; and a number of other forms. It is a little harder than glass, which it easily scratches. It may have, like most other minerals, any color. The purest varieties are either colorless and transparent, or white. Crystals of quartz are usually six-sided like a pencil, and terminate in six-sided pyramids, or points, at one or both ends.

Quartz is not affected by ordinary acids, and is not much changed by heating. To drillers the most familiar form of quartz is that seen in quartz sand and in layers of flint and chert. The latter occur in some limestones and greatly retard drilling on account of the hardness of this mineral. The chert layers in the Edwards limestone are from a few inches to two and three feet in thickness. There are also some chert layers in the Pennsylvanian limestones and in the so called Ellenburger limestone. Small quartz crystals of perfect shape are characteristic of the Redbeds of the Permian in the northwest part of Texas. Sand grains of chalcedony are characteristic of some of the middle Tertiary formations, and have come to be spoken of as "rice sand," from a resemblance of the larger grains to polished rice.

Mica

Mica is a silicate of magnesia. It splits into exceedingly thin transparent flakes, which are elastic, and will spring back when bent. It will not crumble when heated in a flame, as gypsum will. It is not affected by acid. Some mica is black and some has a golden color. It is generally present in several different kinds of crystalline rocks, from which it has been washed and mingled with sand and silt, afterward often hardened into sandstone and shale. Sandstones in the Cretaceous, and also in the Pennsylvanian and the Permian, seldom have much mica; while the sandstones in the Triassic of West Texas and the sands and silts in the Eocene Tertiary are usually very rich in this mineral.

Feldspar

Feldspar is a silicate of potash, soda and lime. There are several kinds of feldspar. It has straight cleavage planes that often show a pearly lustre. Orthoclase feldspar has a pinkish color. It is not quite as hard as quartz, but decidedly harder than calcite. It can be scratched by hard steel, and does not slack after heating to redness in fire. This mineral is the principal ingredient in granite and some other igneous rocks. In sedimentary rocks it is sometimes found as pebbles in some conglomerates, such as those occurring in the Pennsylvanian in north Texas and in the Trinity formation in central Texas, around the Llano uplift.

Hornblende

This is a very dark greenish or almost black mineral with crystalline cleavage. It is a silicate of magnesium, iron, manganese, soda, and potash, and has about the same hardness as feldspar. It occurs in some intrusives, schists and gneisses, underlying the sedimentary rocks in central Texas, and in the Trans-Pecos country.

Augite (and Pyroxene)

Augite is a greenish black mineral. It is a silicate of lime, magnesia and iron. It has straight cleavage in two directions, and is of a hardness very slightly below that of feldspar. This mineral is found in igneous rocks at a few points along the Balcones Escarpment and in the mountainous country west of the Pecos. It does not occur in sedimentary rocks.

Serpentine and Chlorite

Serpentine is a silicate of magnesia and iron containing moisture. It has an oil green color and a hardness varying from below to above that of limestone. Chlorite is closely related to serpentine but contains more iron and alumina. These minerals are the hydrated decomposition products of such minerals as augite and hornblende. They constituted the principal oil-bearing rock in the Thrall oil field and are known to occur as altered intrusives at other points along the Balcones Escarpment and in the Trans-Pecos country.

Glauconite

This mineral is also known as greensand. It is a silicate of iron and potassium, and is from light green to very dark green in color. It will turn black on being heated to redness, and is then attracted by a magnet. This mineral is always found in small rounded grains usually mingled with sand and clay. It occurs in some of the Cambrian rocks, in the Taylor and the Navarro formations of the Upper Cretaceous, and in the Eocene of the Tertiary beds. A well-marked bed of glauconitic greensand is a good horizon marker in the oil fields south of San Antonio.

Calcite

Calcite, or spar, is identical in composition with pure limestone. In most limestones this main ingredient is mixed with some clayey material, and consists of crystals of such small size as to be entirely invisible to the unaided eye. The rock appears to be a structureless mass. The mineral is carbonate of lime, and hence consists of calcium in chemical combination with oxygen and carbon. When burned in a kiln it loses its carbon and forms quicklime. Its hardness is less than that of soft iron and it is easily scratched by a knife. Limestones in which the calcite crystals are large enough to be readily made out by the naked eye are often described as "crystalline lime" by drillers. Most marble is of this kind. The Edwards limestone in the Comanchean series of rocks is characterized by such a coarse crystalline texture. In nearly all limestones places are apt to be found where the original fine-grained rock has been replaced by crystals of calcite of large size which are spoken of as spar. Such spar is nearly always present where underground water courses traverse the formations, and quite frequently they are associated with openings or fissures and cavities in limestone. In the lower part of the Comanchean limestones there are, especially in the southwest part of the state, one or two layers, some two feet thick, in which the crystalline cleavage is continuous through the entire thickness of these layers and cuttings made by the drill from these layers seem to be crushed crystalline calcite.

Dolomite

Dolomite is a mineral slightly harder than calcite. It is a carbonate of lime and magnesia, and is not as readily affected by acid as limestone, which is a carbonate of lime. Dolomite is rare except as it occurs in dolomitic rocks which are particularly common in the Ordovician and the Permian series of formations in Texas.

Gypsum and Anhydrite

Gysum and anhydrite both consist of sulphate of lime. Gypsum contains in addition some water, while anhydrite is free from combined water. When gypsum is heated it loses its water and is said to be calcined. In this state it has the same chemical composition as anhydrite. Neither one of these two minerals effervesces when subjected to the action of acids. Both are softer than calcite or limestone and can be carved and cut with a knife. The crystals of clear gypsum, known as selenite, have acute and obtuse angles, and they have good cleavage in the direction of their length and breadth. They will split into thin leaves, which can readily be bent, but which will not spring back to shape, as the thin leaves of mica do. On account of its resemblance to mica, crystalline gypsum is often incorrectly called "isinglass." Anhydrite differs from gypsum in its cleavage. It breaks straight in three directions which are at right angles to each other. Hence cuttings of anhydrite often have sharp, square angles.

Gypsum occurs in many clays and shales as separate crystals. It frequently has formed from the disintegration of pyrite in marls and other calcareous material. It is usually rare at depths below four or five hundred feet. Below this depth anhydrite mostly takes its place. This mineral occurs in extensive beds in association with the cap rock in our oil fields of the coast, and it underlies extensively the redbeds of northwest Texas.

Barite

Barite is barium sulphate. It is white or colorless and has about the same hardness as calcite, being easily scratched with soft iron. It is much heavier than calcite. If some cuttings of barite be thrown on the fire of a forge, they give a pale yellowish-green color to the flame. Barite has been found in considerable abundance in some of the salt dome oil and sulphur fields on the Gulf Coast, and it is occasionally encountered in the Permian redbeds and in the Comanchean limestones.

Pyrite and Marcasite

Pyrite is an easily recognized mineral. It has a yellow, metallic color, frequently confused with that of gold, is hard enough to scratch glass, and gives sparks when hit with steel. It crystallizes mostly in cubes and octahedrons. Frequently also its crystals present five-sided flat surfaces. Consisting of iron and sulphur, it is natural that this mineral should give a sulphur odor when heated or when violently struck with some substance of sufficient hardness. One variety of pyrite often found in dark clays is known as marcasite. This is usually almost silver white.

Pyrite and marcasite are very common in clays, shales, and slates of all colors except red and yellow. In fact, many red clays have originally had a dark color and they have become red by the oxidation of disseminated pyrite. Pyrite also frequently occurs in limestone and in sandstone. When evenly disseminated in such rocks and in microscopic particles, and when present in sufficient quantity, it gives them a dark color, or may cause them to become even black. Water obtained from such strata usually has the odor of hydrogen sulphide, or of "rotten eggs."

This mineral has a very general distribution in nearly all formations. It occurs in grains too small to be seen with the naked eye and in grains and crystals up to masses several feet in diameter. It is even known to occur in extensive irregular layers several feet in thickness. It is especially apt to occur at contacts between different formations. Layers of this kind have been reported from the base of the Tertiary formations in south and east Texas. They are very hard and exceedingly resistant to the drill. In coal-bearing and lignite-bearing beds, pyrite frequently occurs in concretions or loaf-like bodies, which lie flat with the strata. In the Austin Chalk this mineral often forms round balls from one to two inches in diameter; the outer surface of which everywhere exhibits crystalline faces. In the Del Rio clay and in the Eagle Ford shale, pyrite mostly occurs in irregular clusters of cubic crystals.

Hematite and Limonite

Red and yellow ochre (hematite and limonite) bear somewhat the same relation to each other as do gypsum and anhydrite. Both are oxides of iron. In yellow ochre this oxide is combined with water; while red ochre contains no water in combination. Both are usually soft and are mostly found only in the upper few hundred feet or more of deep explorations. They are for the most part derived either from siderite or from pyrite by oxidation. A test which these minerals have in common with pyrite and siderite is that they become magnetic after being heated to redness. They form the coloring matter in most red and yellow rocks. In east Texas extensive beds of hematite and limonite occur in the Tertiary sediments. Like pyrite these minerals sometimes characterize zones of contact between formations of different ages.

SIDERITE

Siderite is a carbonate of iron. In the impure state in which it mostly occurs it is called clay-iron-stone. In hardness it slightly exceeds limestone. It is also heavier than limestone. It effervesces slowly in acid and becomes magnetic after ignition. Clay-iron-stone has the texture and color of a dark fine-grained limestone. It is the most easily smelted iron ore.

This mineral occurs mostly in so called concretions, which are loaf-like and range in size from the smallest up to several feet in diameter. These concretions are known as turtle-stones, and are most frequent in association with beds of coal and lignite. They are frequently found in marly formations such as the Taylor Marl and the marls in the Midway formation of the Eocene Tertiary. Drillers very generally call them "boulders" when they are encountered in borings.

SALT

Salt is so generally known that it needs hardly to be mentioned here. It crystallizes in cubes and readily dissolves in water. Dissolved in the ground water it occurs generally in the Pennsylvanian and the Permian strata. On the Gulf Coast, it occurs in enormous masses in association with the coastal oil fields, and in the Permian of the west it underlies in several extensive beds the Panhandle and the Llano Estacàdo.

ASPHALT, COAL AND LIGNITE

All these minerals are compounds of carbon and are always black. They all burn. Asphalt readily fuses when heated and gives off an easily recognized odor. Coal and lignite burn, but do not fuse as readily as asphalt. Particles of coal or lignite may be identified by roasting them on a red hot tin plate in a flame, when they glow for a while. Asphalt occurs impregnating many limestones and filling cavities and veins in limestones and shales. In some sandstones asphalt occurs as an impregnation which holds the grains together. Coal and lignite occur in thin layers or thick seams and some kinds of lignite are parts of trunks of trees imbedded in shales and sandstones.

ROCKS

Rocks are classified into two principal groups: igneous and sedimentary. Igneous rocks are formed by the cooling and congelation of molten materials. These may have welled out on the earth's surface or may have been forced up into strata that form the bedrock overlying the region where the fusion occurred. Sedimentary rocks have been formed by the natural and slow accumulation of sediments of any and all kinds, either in the sea or on land. Rocks of this latter kind underlie by far the larger part of the State of Texas, and they are of chief interest to drillers in the southwest.

IGNEOUS ROCKS

The only places where igneous rocks have been encountered by drillers in this state are in the Central Mineral Region in Llano, Burnet, Mason, Gillespie, and Blanco counties; along the structure called the Balcones Escarpment, in Kinney, Uvalde, Medina, Travis, and Williamson counties; and in the mountainous country west of the Pecos. No igneous rocks are likely to be encountered by drilling in any other part of the state. It has recently been claimed that some igneous rock has been found in a deep boring on the Gulf Coast, but the full evidence of this has not yet been furnished. The intrusives in the Balcones belt are practically all of one and the same kind, a very tough, hard black basalt, consisting mostly of augite or hornblende. In many places this rock has been altered, so that it is a very easily drilled green chlorite or serpentine rock, softer than limestone. Such was the main oil-bearing rock in the Thrall oil field. In the Central Mineral Region, the chief igneous rock is granite. This consists of pink feldspar, with some quartz and mica. There are here also extensive areas underlain by gneiss and schist. Originally this gneiss and schist was sedimentary rock, but this has been changed by heat and pressure. It is now crystalline and in part resembles granite. It usually contains more mica than the granite and also contains hornblende. The igneous rocks of the mountainous country west of the Pecos are of many kinds, and can not be briefly described. They belong for the most part to the siliceous types, and range in texture from granite through porphyries, basalts, and lavas to obsidian, or natural glass.

Sedimentary Rocks

The sedimentary rocks may be classified into three main groups: (1) mechanical sediments, which are by far the most common; (2) chemical sediments, which have been precipitated from solutions in the ocean and in lakes; and (3) accumulations of the remains of animals and plants, usually called organic sediments, as animals and plants both are organisms.

The following tables give a general view of the classification of sedimentary rocks.

(1) MECHANICAL SEDIMENTS

TEXTURE	UNCONSOLIDATED	HARD	VERY HARD
Coarse	Gravel	Conglomerate	Puddingstone
Medium	Sand	Sandstone	Quartzite
Fine	Clay	Shale	Slate
Fine (lime)	Lime mud	Limestone	Marble

(2) CHEMICAL SEDIMENTS

COMPOSITION	KINDS OF ROCK
Carbonate of lime	Limestone, tufa, caliche
Sulphate of lime	Gypsum, anhydrite rock, alabaster
Silica	Siliceous tufa, flint, chert
Sodium chloride	Rock salt
Iron carbonate	Clay-iron-stone

(3) ORGANIC SEDIMENTS

COMPOSITION	KINDS OF ROCK
Vegetable material	Peat, lignite, coal, anthracite, graphite
Vegetable and animal material	Asphalt
Shells of microscopic plants	Diatomaceous earth
Shells of microscopic animals	Chalk
Shells of molluscs	Calcareous sandstone, shell gravel, shell breccia
Joints of crinoids	Crinoidal limestone
Fragments of corals	Coralline limestone

In nature, the processes by which these different rocks are made, seldom operate singly and the result is that few if any sedimentary rocks are absolutely pure. While it is very instructive for us to understand these classifications, it is to be remembered that few of these deposits are pure in nature; that is, they are not always exclusively either one kind or another. In practice it is misleading to regard some rocks as belonging strictly to only one of these groups. It is only exceptional conditions that have caused nature to make anything but mixtures. Sand is often mixed with some material that goes to make up limestone. Rock salt is in places found mixed with clay and fine sand. Fragments of shells or crinoid stems may be mingled with other calcareous material or with clay. Calcareous material may be mixed with clay, and clay is often mixed with calcareous material. The latter mixture is so frequent that it has a distinctive name and is known as marl. Coaly material may be mixed with clay to such an extent that it should be called coaly shale or "bone coal." A sandstone may be impregnated with asphalt, in which case it is called asphaltic sandstone. Mixtures of these kinds are so common that it becomes important to exercise caution in making correct determinations of sedimentary rocks, as when two or three ingredients are mingled in nearly equal quantities in the same rock.

It is also true that some sedimentary rocks can be formed by either one of the three processes named. Limestone, one of the most common of rocks, may be entirely the result of mechanical action or silting in water; it may be formed almost exclusively by precipitation out of a solution, or it may result from the growth of organic material. Thus some limestones must be classified as mechanical sediments; others as chemical sediments; and still others, as organic sediments.

GRAVELS, CONGLOMERATES, AND PUDDINGSTONE

In running and turbulent waters, as in streams and on shores, all finer sediments are carried away. But such waters in many places have built up large accumulations of materials of coarse grain, such as gravel and sand. Deposits of this kind are in time consolidated into conglomerate and sandstone.

Gravel rarely occurs in deposits of any great thickness, such as to approach a hundred feet or more. Much gravel is of comparatively recent origin and occurs in the latest sediments which are found in filled river channels in eastern and central Texas. In the region of the Panhandle and the Staked Plains there are quite extensive sheets of gravel in the Pleistocene and Tertiary deposits. These are frequently water-bearing. Some of our deposits of gravels are found on the uplands as well as along stream channels in the central and northern part of the state. Even the most recent gravels are frequently cemented with lime so as to form quite solid rock, or conglomerate.

Conglomerates, which are indurated gravels, occur sparingly in the Pleistocene and Tertiary on the Gulf Coastal Plain. Sheets of conglomerates consisting mostly of flint occur in the Pennsylvanian, especially of northern Texas. A few of these conglomerates contain considerable feldspar in the form of pebbles, and drillers have sometimes reported these as granite, feldspar being present as the principal ingredient in granite. Such rock should be classified as conglomerate, whatever the composition of the pebbles happens to be. Conglomerates are quite frequent in the Triassic formation in the northwestern part of the state. These conglomerates nearly always contain well-rounded pebbles of quartz of a yellowish color, and they are in places characterized by being impregnated with black oxide of manganese. Most of the Triassic conglomerates give good water. One conglomerate, quite like the

Triassic conglomerates, occurs in the Permian redbeds in Tom Green, Coke, Runnels and Taylor counties. Conglomerates consisting mostly of small pebbles of white quartz mingled with sand and lime, occur in the Trinity sand.

Puddingstone is rare in the southwest, being found only in some ancient schists and gneisses.

SANDS, SANDSTONES, AND QUARTZITES

Sand and sandstone present a great variety of rocks. They consist of more or less rounded grains which have been worn to their present size and form. When these are entirely incoherent, we have sand. In such case, the cuttings will consist of loose grains all separated from each other. When the deposit has become somewhat more indurated, the cuttings will frequently show fragments consisting of grains that adhere to each other, and we call the rock *sandstone.* The grains are usually held together either by a greater or less quantity of calcareous material, or of oxide of iron, which are usually present as cement.

In rare cases the sand grains are cemented together by pyrite. Such sandstones are usually black and when ground up by the drill they cause the water to become inky.

The fineness of the grain is spoken of as the texture of sandstones. The variation in this respect is considerable. Some of the sandstones in the Trinity formation consist of fairly fine grains and are soft. These are known to drillers as *pack sand.*

In more than ninety per cent of all sandstones the grains consist of quartz. In some sandstones the grains are calcareous. Such is the Anacacho limestone in the Upper Cretaceous.

Micaceous sandstones are such as contain mica. Standstones of this kind are usually fine-grained. The Triassic sandstones in northwest Texas are as a rule highly micaceous. Sandstones occurring in the Pennsylvanian and Permian are almost free from mica in the central part of the state. West of the Pecos mica is more frequent in the Pennsylvanian sandstones than farther east. Sandstones of the Cretaceous in the southwest are almost devoid of mica.

Ferruginous sandstone contains limonite or hematite, which colors them red. Red sandstones of this kind are most common in formations that contain coal or lignite, and also in formations that contain salt, as in the Permian in this state. The ferruginous material has been in most cases introduced by water flowing through the sands, long after the sands were made.

Sandstones are usually more or less porous. When these porosities have been filled with asphaltic material they are called *bituminous sandstones.* When the porosities are filled with oil they are spoken of as oil sands, and when filled with gas, they are called gas sands. When they are filled with water, they are called water sands; when entirely empty, they are called dry sands; and when filled with calcareous material we speak of them as *cemented sandstone.*

Some sandstones have been so greatly hardened by pressure or by infiltration of siliceous material that they will break through the grains rather than around them. This is the distinguishing feature of *quartzite.* Rock of this kind occurs in association with some schist and gneiss in the region of the ancient altered rocks in the central part of Texas. and also locally in Tertiary sands on the Gulf Coast Plain. The Trinity Sand has also been changed to quartzite in a few widely separated areas of very limited extent.

CLAY, SHALE AND SLATE (*Argillites*)

Argillites is a general name used to include a large group of sedimentary deposits, which when first formed were mud-like or clay-like in nature. They consist of the silt and clay brought into the sea and other waters by rivers and smaller streams. These materials finally settle on the bottom of the waters. Rocks resulting from such deposits consist of mineral particles of small size, from the very finest sand down to the smallest infinitesimal sizes. The coarser argillites may be described as silty or even sandy clays, or shales. In mineral composition there is also considerable variation in this class of sediments. They differ from sands and sandstones in containing more aluminum-bearing material and less of silica. Sands consist mostly of quartz while clays are largely derived from the more easily crushed and softer minerals, such as feldspar, and hornblende, and from the insoluble residues of limestone and other disintegrated rock.

The distinction between clay, shale, and slate is based on hardness. Clay is soft and plastic. All argillites, when first deposited, have been clay. In time clay will harden under the burden of thousands of feet of overlying formations. All argillites of the latest age, the Quaternary, are yet soft clay. Argillites of Tertiary age are in the condition of clay, except in mountainous regions where they have been subjected to heat and pressure. The same is true to a lesser degree of the argillites of the Cretaceous, the Jurassic and the Triassic ages, which are still older than the Tertiary. In the Permian and the Pennsylvanian and other yet earlier Paleozoic formations, most clays have been hardened to a condition we find in shale, and in mountainous regions this has acquired the yet greater hardness we find in slate. In the crystalline rocks of the Archean formations nearly all clay has been changed to the condition we designated as slate or to some rock still harder than this.

Of all rocks, clays and silts are most easily penetrated by the drill. Three and even four hundred feet of hole have sometimes been made in twenty-four hours through such deposits. But at depth, very fine-grained clays and sometimes silty clays cause much trouble by "caving." Some clays which cave are the so called "joint clays" or "slip clays," which are cut by slippery joints that cause the ground to give way and fall into the hole from its walls. Some fire clay is of this kind. These clays are specially apt to be found for some distance below seams of coal and lignite and below layers of very black, laminated and resistant shale, often erroneously called "slate." Some caving shale breaks into long and slender splinters and this has by some been called "pencil cave" and "shoe peg" shale. The best practical distinction between clay and shale is to classify as clay only such material as is nearly entirely soft and plastic and to regard as shale any argillite which to some considerable extent comes up from the boring in solid broken fragments.

Owing to the presence or prevalence of certain mineral ingredients, different kinds of clay, shale and slate are to be noted.

Marl

A clay may be described as calcareous, when it contains sufficient calcareous material to cause slow effervescence on the application of acid. A clay containing a considerable amount of calcareous material is called marl, which may or may not also contain some red or yellow oxide of iron. Nearly all the clay formations of Cretaceous age in this state are marly. Shale and clay in the Pennsylvanian and the Permian are quite commonly devoid of a calcareous ingredient. In the Pleistocene deposits we find both marls and non-calcareous clays.

Fire-clay

Fire-clay is free from lime, as a rule. It occurs in beds which were at one time exposed and leached at the surface and later, perhaps, buried under peat which since has changed to lignite or coal. In texture, fire-clay is quite variable, from the finest clay to silty and quite sandy clay. Fire-clays occur especially in coal and lignite-bearing formations, such as the Pennsylvanian, parts of the Eocene Tertiary, and the coal-bearing beds of the Cretaceous on the Rio Grande.

Fuller's Earth

Strata of white kaolin-like clay occur in the lower part of the Taylor marl and at several levels in the early and middle Tertiary. These strata are, for the most part, deposits of volcanic dust, which has been hydrated, and which are known in some cases to be suitable for use as fuller's earth. Fuller's earth is also found in the Tertiary.

Micaceous Clay and Shale

The shales and clays of relatively coarse texture, such as silts, sometimes contain much mica and may be called micaceous shales and clays.

Ferruginous Clay and Shale

In the Permian of northwest Texas much clay, shale, and silt has a red color due to the presence of oxide of iron. These deposits have long been known as the "red beds," owing to their red color. Red clays and shale occur also in the Pennsylvanian as well as in deposits of other ages.

Bituminous Clay and Shale

This name is applied to argillaceous deposits containing bituminous materials such as oil or asphalts. They are nearly always of a dark color or even black, and generally give "rainbow" colors and even stronger showings of oil, when explored in drilling.

Carbonaceous Clay and Shale

Shales containing coaly material in a finely comminuted state are dark or even black and grade into impure coal, "bone coal." Shales of this kind are common in the Pennsylvanian formations, and also occur in association with lignite in the Eocene Tertiary.

Soapstone

This name is often incorrectly given to light-colored shale. No soapstone is found in the sedimentary rocks. The rock known by this name is a result of metamorphism and occurs mostly only in association with crystalline rocks.

Gumbo

Any clay which will "gum" or adhere to the drill, is called gumbo. The term is in general use mostly among drillers on the Gulf Coast.

LIMESTONES

A limestone is a rock that is composed chiefly of carbonate of lime. Rocks composed of carbonate of lime and of magnesia are known as magnesian limestones, or dolomites. The amount of magnesia in a dolomite varies considerably, from eight to thirty per cent. Almost all limestone contains a small ingredient of clay and siliceous material. The purest limestones have less than one per cent of these ingredients. In some limestones they may amount to as much as twenty per cent, or even more. A calcareous rock that contains more clay than carbonate of lime or magnesia is usually called a marl, especially when not indurated.

The usual color of limestone is light gray but a limestone may have any color, from the many impurities which may enter into its composition. Some limestones are colored red from the presence of iron oxide. This red may vary from yellow and orange, through red to purple. Limestones may be green or greenish from the presence of other compounds of iron, as in the case of glauconitic and chloritic ingredients. The cuttings of limestones that come from below the level of moisture in the ground very generally have a bluish gray tinge, mostly owing to the presence of ferruginous material. Under the influence of weathering such limestones acquire the familiar yellowish, straw color. Some limestones are dark gray or even black, due in some cases to the presence of manganese, pyrite or in other cases to the presence of bituminous material. As regards their texture, limestones vary greatly. Most limestones which are not dolomitic have a fine texture and under the impact of the drill they break into fragments that are more or less equal in diameter in all directions, though there are many exceptions to this rule. Some limestones are thinly laminated and break into flaky fragments. Some limestones are highly porous and others again are quite compact, and break with smooth and curving fracture almost like flint. The hardness of limestone is such that it can easily be scratched with soft iron. Soft limestones can be scratched with the finger nail. The usual progress of drilling in a limestone is at the rate of ten feet in twelve hours, with a standard rig, and a little less with a rotary rig, using a Hughes bit. It is said that a pure limestone has a tendency to wear the angles of a drop bit so as to round its cutting edges.

Drillers usually identify limestones by mere optic examination of the cuttings. In many cases this is unsatisfactory. Beds of gypsum and anhydrite have often been in this way identified as limestones. The only reliable and quick test by which limestone may be identified, is by the application of dilute hydrochloric acid. This is best done by placing a few drops of the acid on a flat glass and letting a clean washed small fragment of rock fall in this acid. Fragments of limestone will invariably effervesce in the acid, and the effervescence is always prompt and active. Dolomite effervesces slowly. The finer the fragments the more violent is always the effervescence.

Varieties of Limestone

When examined closely, hardly any two limestones will be found alike. With practice, some of the varieties of limestone can be distinguished with the naked eye, or at least with a hand lens.

Oolitic Limestone

Oolitic limestone consists of small, almost perfectly spherical grains of the size of fish roe down to fine sand. When the oolitic grains are of sufficient size, the rock is easily identified with the naked eye. Some oolites consist of grains so small that they can be identified best in a thin section examined under the microscope. The ooliths are believed to have acquired their round form by rolling and by the accretion of calcareous material present in abundance in the water where the rock was formed. It is also believed that in many instances the formation and growth of ooliths have been influenced by microscopic organisms. In many ooliths it can be made out that the crust of the grains has been deposited around a small center of mechanical origin. Oolitic limestones occur in formations of all ages. The proportion of ooliths to the mass of the rock varies from small to large fractions. Under the impact of the drill, oolitic limestone is to a large extent separated into the original oolitic grains and it is not infrequently mistaken for sand. In this state horizons of oolitic material occur at several geological horizons.

In the lower part of the Ellenburger limestone such rock has in places been silicified, so that we find it containing layers of oolitic chert. The ooliths in this horizon are relatively large and almost perfectly spherical. They are also trenchantly marked off from the matrix in which they are imbedded. In the Pennsylvanian, oolitic limestones are very rare, but again in the Permian, especially of the western part of the state, they are frequent. Some occur in the Permian redbeds. In many of these Permian limestones the ooliths are of small size, and not always clearly defined in outline. In the Comanchean and Upper Cretaceous, oolitic limestones are practically absent. They are rarely if ever found in limestones of Tertiary age in the Southwest.

Shell Breccia

Some limestones consist of fragments of shells which have been broken up and more or less worn by water currents. These may be called shell breccias, organic conglomerates, or organic sandstones, according to the degree of wear of the organic fragments from which they are made. Many limestones are a mixture of fine calcareous slime material and fragments of organic bodies. Such are most of the limestones in the Pennsylvanian. The Anacacho limestone of the Upper Cretaceous formation is for the most part an organic sandstone with coarser layers that can be classed as shell breccias. Rocks of this kind frequently take their name after the bulk of the organic materials of which they are composed. Coral limestone consists mainly of coral fragments. Crinoidal limestones consist of joints of crinoid stems. Limestone of this latter kind is known in Texas only in the Pennsylvanian formations.

Chalk

In some parts of the sea, in the past as well as at present, foraminifera have existed in such abundance in the sea that their minute shells have formed an ooze on the bottom of large areas in the ocean. When such deposits are consolidated, they form the porous, soft rock known as chalk. When exposed and weathered, chalk is usually of a white color. When encountered in wells it is sometimes of a bluish-gray color, and so soft as to be only slightly different from some marls. Chalk is confined almost exclusively to the Austin formation in the upper Cretaceous.

Lithographic Limestone

This is characterized by an exceedingly fine and uniform texture and the name may be applied to any limestones of this texture. So far as known, no lithographic limestone suitable for use in the arts has been found in Texas, but limestones of a very fine texture characterize at least two geologic horizons. One of these horizons is the upper part of the Ellenburger limestone; another is the Buda limestone of the Cretaceous. Thin limestones of like texture occur also at certain horizons of the Permian above the Clear Fork formation. These are thin and usually somewhat impure. Some of them are characterized by a peculiar delicate light blue color.

Dolomite

Dolomite and dolomitic limestones are characterized by definite and clear crystallization of the mass. On the application of acid, effervescence is slow, unless the rock is finely pulverized. The crystals vary considerably in size but are usually uniform in this respect in individual layers and beds. Usually dolomitic limestones are a little more resistant to the drill than other limestones. Dolomitic limestones make up the lower two-thirds of the Ellenburger formation. Locally there are some layers of dolomitic limestone in the lower part of the Comanchean. Dolomitic limestone is rarely found in the Pennsylvanian and in the Upper Cretaceous. It is abundant in the Permian.

Caliche

Caliche is a white, porous rock, indurated to any extent, or perfectly floury. Such deposits are formed by the deposition of lime from water evaporating from the surface of the ground or from the water table below the surface. Usually it occurs as a part of the surface soil. In the region of the High Plains of northwest Texas it underlies the yellow adobe soil at depths varying from zero to thirty or forty feet. In this region it is soft white rock, somewhat resembling chalk, and it is locally known as the "rim rock." It is made up of exceedingly fine calcareous crystals of carbonate of lime, and effervesces with great briskness on the application of acid.

Travertine

Travertine is a crystalline or occasionally structureless calcareous rock of somewhat more than common hardness. It is sometimes encountered as fillings in underground caverns and is in many cases colored red by the presence of ferruginous material. On account of its crystalline structure and its color it has in some cases been reported by drillers as granite.

Bituminous Limestone

This is a limestone impregnated with asphalt or other bituminous material. It can usually be recognized by its odor upon heating, or upon crushing after it is thoroughly dried. Limestones so impregnated are usually quite resistant to the drill. For the most part they are thin. The thickest known are in the Permian of West Texas, near the middle of the Permian section.

GYPSUM AND ANHYDRITE ROCK

Any large accumulation or bed of these minerals is to be regarded as rock and should be identified by drillers in describing the ground explored.

When sulphate of lime is precipitated in the sea, it may result in the formation of either of these two rocks. Both are characterized by their softness. They can be scratched with the finger nail. Neither of the two is attacked by acid, and this furnishes a ready method for identification. A soft sedimentary rock which resembles limestone in texture and which will not effervesce in acid, is in nine cases out of ten either gypsum or anhydrite. Anhydrite may sometimes be known from its behavior in drilling. When it is ground up into very fine powder by the drill, it is apt to take up water and set like plaster of Paris, adhering strongly to the bit, even to such an extent as to interfere with the work. Anhydrite as well as gypsum occurs in association with the salt beds of the salt domes in the coast country and there they are, like the salt deposits, limited in horizontal extent but often quite deep. Usually the anhydrite occurs under the cap rock and always above the salt. It has frequently been reported as limestone by drillers in the coastal fields. While small crystals and small bodies of gypsum and anhydrite may be found in many clays, it is only in the Permian and perhaps some of the Comanchean beds in the western part of the state that these minerals exist as extensive formations. Most of the sulphate of lime in the Permian sea seems to have been deposited originally in the form of anhydrite, for it is seldom that any gypsum exists in these beds below 300 or 400 feet, from the surface. Below this depth nearly all sulphate of lime is anhydrite. Extensive beds of anhydrite underlie the Panhandle and the Llano Estacado and extend nearly to the central part of the state in the lower part of the Permian. Anhydrite as well as gypsum has frequently been reported as limestone. The most fine grained kinds of gypsum and anhydrite are also called alabaster rock.

ROCK SALT

Rock salt is what the name implies, salt in large masses. In the salt domes of the coast these masses are known to be several thousand feet in thickness. They do not here reach any great distance horizontally, but are limited to the salt domes, which seldom extend more than a few miles in any direction. The only formation which contains rock salt in extensive horizontal beds, is the upper part of our Permian in the Panhandle and in the Llano Estacado regions. Here we find salt beds from a few up to 300 feet in thickness, evidently extending scores of miles underground. They represent evaporated brine from embayments in the sea in which the Upper Permian was laid down. At times in this sea, salt was evidently accumulating at the same time with fine sand and silt, and the result is that we find beds which consist of half salt and half silt. In the Spur well, such beds were some scores of feet in thickness.

In drilling through rock salt, especially with a rotary, it sometimes happens that the ground-up rock is entirely dissolved by the water used. In such cases it has sometimes puzzled inexperienced men that there are no "returns." The rock is all dissolved and there are no cuttings from the ground penetrated.

FLINT AND CHERT

All calcareous muds that have been consolidated into limestone contained originally some siliceous material. Under the influence of moisture present in the ground, different minerals have a tendency in all rocks to segregate. Each mineral tends to form separate bodies of its own kind. By a process somewhat resembling the growth of crystals, there are thus formed frequently in sedimentary rocks bodies of materials of different composition from the mass of the rock itself. These bodies are called concretions. Their shape usually is more or less determined by the structure of the rocks. In bedded rocks there is a tendency for concretions to be flat or loaf-like. When the siliceous materials present in limestones have gathered in concretions, we call these bodies flint or chert. Concretions of this kind have formed in many limestones and are frequently characteristic of certain layers in these limestones. Flint has a hardness a little in excess of the steel in a file. It will cut glass and indent some steel. It may have any color, but is usually gray or grayish-white when found below the surface. It can usually be known from its fine texture, and from its tendency to split into very sharply angular fragments. When viewed with a magnifying glass the chert is translucent along thin edges. As quartz is not affected by acids, flint and chert can readily be told from limestone when present in cuttings. With practice it is readily recognized without any test. Flint is frequent in the Pennsylvanian limestones and in parts of the Ellenburger limestone of the Ordovician. It is infrequent in our Permian limestones, but quite abundant in the Edwards limestone of the Comanchean rocks. In the Upper Cretaceous, flint is rare, and it is almost unknown in our Tertiary sediments.

CLAY-IRON-STONE

Just as silica is present in limestone, so we have carbonate of iron present in shales. In some shales this carbonate of iron is distributed throughout the deposit, while in other cases it has formed concretions and gathered together into nodules and loaf-like bodies ranging in size from a few inches to many feet in diameter. Occasionally an accumulation of carbonate of iron forms separate layers, which, no doubt, were laid down originally in their present condition. When heated in a flame, carbonate of iron is reduced in part to metallic iron and becomes magnetic, so that if a magnet is passed through the cuttings the roasted fragments of clay-iron-stone will be picked up. It is also attracted by acid but the effervescence is much more slow than it is in the case of limestone and dolomite. Clay-iron-stone is of a fine texture and gray in color. It is quite hard and very tough and resistant to the drill. Most clay-iron-stone concretions are traversed by thin veins of calcite which is frequently colored brown from the presence of iron.

Concretions of this kind are frequent in all dark clays and shales. Drillers often record them as boulders. They are, of course, not true boulders, since they have grown into shape in the place where they are found. Concretions of carbonate of iron occur in a few horizons of the dark shales of the Pennsylvanian. They are frequent and often of large size in the Taylor Marl and in the Navarro formation of the Upper Cretaceous, and they are quite common in the clays and marls of the Tertiary. The true nature of these formations can easily be ascertained by the fire test, as already mentioned.

THE PRINCIPAL FORMATIONS IN TEXAS

INTRODUCTORY

What is known among geologists as "formations" are extensive sheets of more or less similar rock material that have been deposited under somewhat similar conditions, over large areas. Just how much is to be called one formation, is to a great extent dependent on the judgment of those who describe the formations. In cases where the formations are clearly marked by difference in the nature of the materials of which they consist, or by differences in the fossils they contain, there is seldom any disagreement as to their limits. The horizontal extent of formations is very variable, ranging from a few miles to several hundred miles. As the existence of water, oil, and other minerals, which are sought by drilling, can to some extent be foretold from the nature and position of the formation in which they occur, it is of much importance to the practical driller to be able to distinguish the different formations he penetrates. This is usually done by examining the cuttings as the drill descends. Such identification of formations requires a most extensive as well as intimate knowledge of the rock of which they consist. In making them, the driller has an advantage over the geologist in that he has opportunities to make frequent examination of the materials through which he drills. On the other hand, the geologist usually has the advantage in possessing extensive knowledge of the formations from examining them in exposures at the surface, and in widely separated places. This enables him to better interpret his observations on the material brought up by the drill. It is highly desirable that the efforts of drillers and of geologists should be combined in securing exact knowledge of our formations as they exist underground. These notes are written in the hope that they may be of some aid in this direction. They are brief descriptions of the principal formations which are encountered by drillers in the southwest.

In these notes, the formations have been described in order from above downward. This is the order in which the driller encounters them. It is hardly necessary to call the attention of the reader to the fact that all of these formations, from the top to bottom, are not found at any one place. Some are always absent.

The latest formation overlies the older rocks almost everywhere, especially in stream valleys and on the coast. There is a great accumulation of late deposits along the Gulf Coast. Formations of earlier age than these are encountered, superficially, in succession further inland away from the Gulf, until we come to the Central Mineral Region in Llano and surrounding counties. Here we encounter some of the very oldest rocks. From this point northwestward we find again successively younger beds out to the northwestern part of the state, where recent deposits overlie the older ones on the High Plains. In the region west of the Pecos River, the country has been broken up into parts of relatively small size, and we find all the formations outcropping at the surface within quite short distances of each other.

Everywhere it will be found that some of the formations described are missing, in local sections. Gaps of this kind are in many cases due to earlier periods of erosion, by which some formations were removed before later ones were deposited. In such case the beds below and above the missing member or members, are said to be separated by unconformities.

A peculiar condition exists on the coast. By far the greatest part of all borings on the coast have been made in the so called "salt dome oil fields" in that region. More than a score and a half of salt dome structures have been found on the coastal plain, mostly within a hundred miles of the Gulf Coast. These structures are dome-like and cover relatively small areas from one to three or four miles in diameter. Their origin is not yet fully understood. They may be said to resemble plug-like uplifts of ground, where beds lying elsewhere at a depth of 3000 to 4000 feet have been pushed up to within 1000 feet of the surface or even up to the surface. Where most of the drilling in the Gulf Coast oil fields has ben done, the original position of the formations is therefore quite destroyed and the descriptions and measurements which are given in the following notes on the Pleistocene and Tertiary do not apply to the positions which these formations have in the salt dome oil fields, where most drillers have had their experience. They apply only to the positions that these rocks occupy in the wide tracts which separate these domes from one another.

PLEISTOCENE AND RECENT FORMATIONS

Our latest deposits are made up of the soil, and of alluvial sediments of silt, sand and gravel along streams everywhere. On the Gulf border, littoral sediments, such as clays, sands, and gravels, and mixtures of such materials of varied color, extend to depths of from a few to 1600 feet. These thin rapidly inland, and disappear entirely in from fifty to ninety miles from the Gulf. Logs of wood, shells like those from the present Gulf waters and bones of larger animals, such as elephants, horses, the bison, and the deer, are occasionally to be found. In a recent boring in Kleberg County, the minute oval and spirally marked spore-fruits of *Chara* were found in cuttings coming from 800 feet down in these beds. The High Plains of the west are also covered with loam sand and gravel of this age.

Almost everywhere the Pleistocene and recent formations are entirely unconsolidated.

THE TERTIARY FORMATIONS

The tertiary in Texas measures about 5000 feet in greatest thickness. It underlies the Pleistocene of the Gulf Coast and extends in a belt diagonally from Louisiana to Mexico. This belt is about 120 miles wide on the Rio Grande, 70 miles wide in the middle of its course, and 180 miles wide in the east part of the state. The oldest formations of the Tertiary outcrop farthest inland and the youngest formations appear nearest the Gulf. The entire Tertiary dips toward the Gulf at an average rate of from twenty-five to seventy feet per mile.

The Tertiary can be divided into three parts: the upper, the middle, and the lower.

THE UPPER TERTIARY

On the coastal plain, the Upper Tertiary consists of deposits much like those of the Pleistocene, such as clays of various shades of color, sand, and gravel. The clay is often reported as gumbo by drillers. In cuttings from this part of the Tertiary, fragments of bone and of silicified and lignitized wood are sometimes found. Small shells of fresh water molluscs (such as clams and snails) and fragments of larger molluscs are somewhat common, in cuttings from these beds on the coast. Some of the sands are coarse, some fine in texture. In the clays, small calcareous concretions are frequently found. Inland, the upper Tertiary deposits are mostly old alluvial accumulations yet but little known. Their thickness is very variable, at different points, but probably nowhere exceeds four hundred feet in the interior of the state.

THE MIDDLE TERTIARY

On the Gulf Coastal Plain, the Middle Tertiary consists of two divisions. The *Dewitt formation,* from 0 to 800 feet thick, lies uppermost. It consists mostly of slightly indurated sand with some streaks of clay. These sands and clays often contain bones and ancient oyster banks. The lower part of the Middle Tertiary, known as the *Fleming Clay,* is from 200 to 400 feet thick. It is very generally reported by drillers as "gumbo," as it is fine-textured and sticky. It is noted for containing many small nodules or concretions of calcareous material.

In the High Plains of the Panhandle, and the Llano Estacado, the Middle Tertiary is represented by fairly loose sands and clays, mostly less than 100 feet thick, and from light gray and greenish-gray to brown in color. Fragments of bones of mammals are quite frequent.

The *Catahoula sandstone* may be said to be the lowermost formation of the Middle Tertiary, measuring from 500 to 800 feet. It is coarsest below and contains some clay above. The coarser sand of this formation, especially near its base, is sometimes characterized as "rice sand." This is because many of the larger sand grains are oval. They consist of a slightly translucent quartz resembling agate or chalcedony. The sands of this formation are usually soft but locally they may be hard. Fossil wood is quite common in this formation.

THE LOWER TERTIARY

The Lower Tertiary occurs only on the inner Gulf Coast Plains, where it is represented by no less than seven different formations.

Under the Catahoula is the *Jackson formation* in Sabine, San Augustine, and Angelina counties. It consists of some 250 feet, or less, of marly clay with sea shells and large calcareous concretions, usually known as "boulders." It can often be identified under the microscope by the presence of many angular grains of volcanic dust.

Next in downward order is the *Yegua clay*, ranging from 375 to 750 feet in thickness. The clay is greenish-gray and dark gray. It contains lignite in places and is characterized by concretions and crystals of gypsum, and by frequent minute siliceous tests of diatoms, some of which are of relatively large size and spherical in form.

The Yegua is underlain by the *Cook Mountain* formation, which consists of sand and clay. Both the sand and the clay often contain green grains of glauconite, frequent fossils, many concretions, and often continuous layers of clay-iron-stone. Thickness, 400 feet.

The underlying *Mount Selman formation* is some 350 feet thick and consists of materials somewhat like those of the Cook Mountain, but in part red, and with more lignite.

The *Wilcox formation* measures some 1000 feet in thickness. This formation consists of marly clays and beds of sand some of which yield much water. There is also much lignite and some glauconite. Fossil shells and plants are frequent in some of the marl.

The *Midway* is the lowest of the Tertiary formations. From Hopkins to Falls County this formation contains considerable white limestone, which is an indurated shell breccia or a sandstone made up of mostly worn organic grains mingled with some foraminifera, and cemented by a calcareous matrix. The greater part of the formation which is some 400 feet in thickness consists of thin-bedded marly clays, with imbedded small fossils and black shreds of vegetation. Minute tests of foraminifera are quite common.

THE UPPER CRETACEOUS FORMATIONS

The Upper Cretaceous formations are a succession of clay, shale, or marl, chalky flags, and sandstone. They outcrop in a belt extending from the northeast corner of the state westward to beyond Dallas, from there south to San Antonio, and thence west to Del Rio. The thickness of the entire Cretaceous is near 5000 feet. In east and central Texas, the formations of this age dip toward the Gulf at a varying rate from a few to some eighty feet to the mile, and south and east from the indicated belt they pass under the deposits of Tertiary age, going deeper and deeper as we approach the Gulf. Here they may lie more than 5000 feet below the surface. West of the Front Range, the Cretaceous occurs north of and around the Chisos Mountains, between the Chinati, the Eagle, and the Quitman mountains, east of Davis Mountains, and in some other less extensive areas.

The latest of the Upper Cretaceous is known as the Tornillo beds and these consist of vari-colored, red, yellow, and greenish-gray and dark clays. These occur in a belt surrounding the Chisos Mountains, and are of little interest to drillers.

The Tornillo clays are underlain by some coal-bearing beds, called the *San Carlos* beds, in Presidio County and the *Rattlesnake beds* in Brewster County. These may be the equivalents of the *coal-bearing beds* at Eagle Pass. So far these formations have been but little drilled. With the overlying *Escondido* beds in Maverick County, they must have a thickness of at least a thousand feet in the southeast part of Maverick County. The clays are mostly dark, tough, and gumbo-like. These alternate with soft sandstones from 10 to 100 feet in thickness. These are frequently strongly cemented with calcareous material and again quite soft, almost loose sands. There are also layers of oyster shell beds.

In the Anacacho Mountains and east into Medina County the Eagle Pass coal-bearing formation seems to be replaced by the *Anacacho limestone.* This formation is some 400 feet thick in the Anacacho Mountains, but thins gradually to the east. It consists of a white limestone composed of some oolitic material, much worn calcareous beach sand of organic origin, and some fine shell gravel. For the greater part, the rock is strongly cemented by infiltrated and other fine-textured calcareous material. It is the thickest oolitic limestone among our Cretaceous formations. The somewhat open textured beach gravel in the lower part of the formation in Uvalde County contains the Uvalde asphalt.

Below the coal-bearing beds of the Upper Cretaceous we have in north Texas the *Navarro* beds, which are regarded as measuring some 300 or 400 feet in thickness. These are mostly gray marls and sands which nearly everywhere contain some glauconite, by which they are usually recognized.

In the north, the Navarro beds are not easily to be separated from the underlying *Taylor marl* by the examination of cuttings. This formation is one of the well known "gumbos" of the upper coastal plains. It is an easy drilling formation, through the 700 to 800 feet of which rotaries have been plunged in some cases in less than three days in the Corsicana, the Thrall, and the Caddo fields. In some places small fine-textured sandy layers occur in the Taylor marl and such sands are usually glauconitic, as is also frequently the marl itself. Occasionally small teeth of fish come up with the returns from the upper third of this formation and throughout nearly the whole occur prisms of calcareous material from shells of Inocerami. The marl is almost invariably more or less bituminous.

The *Austin Chalk,* from 200 to 300 feet in thickness, underlies the Taylor marl. This is usually easily recognized by its texture, its light color and its softness. In some places it is bluish gray. This can also be recognized by the abundance of small formaminifera which it yields on trituration and washing. The prisms of shells of Inocerami are always present in the cuttings, and frequently also larger pieces of these shells. The Austin Chalk is a quite uniformly developed formation wherever it occurs in the southeast two-thirds of the state. West of the Pecos it is less easily distinguished from the overlying Taylor and the underlying Eagle Ford.

The *Eagle Ford* formation is quite unequally developed in different parts of the state. To the north and northeast it merges downward into the Woodbine sands and consists, like this, of marls, clays and sands. Here it is several hundred feet thick. Southward it gradually becomes thinner until at Austin it is less than 50 feet. Westward from San Antonio, it again increases in thickness. Following it beyond the Pecos River, we find that it measures some 600 feet. From Austin, south and west, it becomes more and more calcareous and west of Devil's River it is mostly thin-bedded limestone. This formation is everywhere more bituminous than other parts of the Cretaceous and this feature is most marked where it has the least thickness, as from Waco to San Antonio and from San Antonio to Del Rio. It nearly everywhere gives showings of oil. Within the same limits it consists in part of black marly shale containing in places as much as ten or even twenty per cent of oil or other volatile bitumens. This black shale and also the more calcareous layers which approach limestone or sandstone, can usually be known in cuttings by the occurrence of fish scales or other fish remains on flat cleavage fractures. Such scales are less frequent in the formation in the north and in the west, but they can generally be found in cuttings from these localities also, if persistently looked for. In Bexar County many drillers record this formation as "lignite" in their logs.

The Eagle Ford is underlain from Waco northward by the *Woodbine* sands and clays. These are not always readily to be separated in cuttings from the Eagle Ford. In the Woodbine, sands are more prevalent than in the overlying formation, and this formation generally shows some traces of plants, such as shreads of leaves and pieces of wood, while it rarely has any fish remains. Pyrite is common in places near the base of this formation.

THE LOWER OR COMANCHEAN CRETACEOUS FORMATIONS

The Comanchean Cretaceous (Lower Cretaceous) is essentially limestone with some marly clay and sandstone. It is one of the most extensive series of rocks in Texas, covering a belt of country from Gainesville to north of San Antonio and from there westward over the entire Edwards Plateau to the Front Range and into New Mexico. Smaller, but quite extensive areas occur west of the Front Range. Its thickness ranges from zero to at least 1500 feet in the Big Bend Country. It has been drilled quite extensively, mostly for water.

Different ones of the Comanchean formations can be separately identified.

South of Waco and westward past San Antonio and out to Brewster County, the *Buda* limestone underlies the Upper Cretaceous. This is a pure white and almost compact limestone, seldom less than thirty or more than seventy feet in thickness. It is sharply marked off from the dark Eagle Ford clay above and from the soft Del Rio clay below. No other formation in Texas compares with the Buda in the combination of its white color and fineness of texture.

The *Del Rio* clay, which underlies the Buda, has a great capacity for caving. In places it is absent and, where present, it varies in thickness from a few feet to two hundred feet. This formation can almost everywhere be identified by a little "ram's horn" shell, *Exogyra arietina,* and another equally common shell, which looks like a very short string of small beads, *Nodosaria texana.* Both can generally be washed from the returns, from this clay.

In the central part of the state the *Georgetown,* which underlies the Del Rio, consists of frequent alternations of limestone and marls usually full of shells. To the southwest this is replaced by some very compact limestone.

Under the Georgetown follows the thickest and most extensively developed member of the Comanchean, the *Edwards* limestone. This measures from fifty to four hundred feet in thickness. It is quite uniform in character, partly of coarse crystalline texture, in some places cavernous, and almost everywhere it contains a few persistent layers of gray flint.

Below the Edwards there are again some changes to marly material and often some strata containing fine sand, the *Paluxy* sands, which are generally water-bearing, and are oil-bearing near South Bosque. At this depth the *Glen Rose* formation begins. This can usually be identified from its cuttings by the appearance in them of some small circular, concavo-convex, dark, disk-shaped fossils, *Orbitulina texana.* The limestones below the Edwards are quite generally noticeably finely dark-speckled, and are almost invariably darker than the overlying rock. They measure, with the interbedded marls and sands, from three hundred to nearly a thousand feet in thickness.

The basal deposits of the Comanchean consist of mostly blue and partly red marls and white, gray, or yellowish sand, varying from packsand to gravel. They are mostly quite soft, but are in a few places very hard, practically quartzite. This sand, which is the *Trinity* sand, makes the great water-bearing formation in northern, and parts of central Texas.

THE JURASSIC FORMATIONS

Deposits of this age, consisting chiefly of limestone with some conglomerates and dark shale, are known only in the Malone Mountains and are of no general importance to drillers in Texas.

THE TRIASSIC FORMATIONS

This consists largely of red clays and sand, with which are also some gray sands and some conglomerates.

The Triassic underlies the greater part of the Panhandle and the Llano Estacado, where it overlies the Permian and extends in detached outliers as far east as to Glasscock County at the south and beyond Dickens and Amarillo to the north. The sands and conglomerates of these beds usually have good water. These sands are mostly highly micaceous. The conglomerates in the lower part are characterized by well rounded yellow or white quartz pebbles. All parts of the formation are apt to contain logs of trees changed to lignite or in a silicified condition. Some gypsum is also found, and black manganese oxide is not infrequent. The Triassic is not known to have any limestones.

THE PERMIAN FORMATIONS

The greatest known thickness of the Permian is in the Glass Mountains, where it measures some 9000 feet and consists largely of limestone, in part dolomitic. Permian of the same general character occurs also in the Guadalupe Mountains, north and east of the Chinati Mountains, and probably in some other localities west of the Pecos.

The Permian beds which are apt to be of most interest to drillers occur on the Plains. This formation extends west from the principal Pennsylvanian area to the Pecos River and to the east escarpment of the Panhandle High Plains and the Llano Estacado. West from this escarpment it is overlain by the Triassic and other later formations, rising again in New Mexico. How far south it underlies the Comanchean north of the Rio Grande and east of the Pecos River is not known. It has been found in a boring at Sheffild. The upper 1500 feet of this part of the Permian consists largely of red marls and clays commonly known as the "red beds" which also contain beds of anhydrite and gypsum and quite frequent beds of salt, some of the latter measuring as much as a hundred feet in thickness. These beds are mostly eroded away east of the line joining Ballinger, Abilene, and Petrolia. The lower part of the Permian, which underlies the "red beds" in this region and which appears on the surface east of the line indicated as far as to the Pennsylvanian area, consists of mostly blue, in part reddish, and purplish shales, clays, and marls; and there are gray, red and white sandstones, which are nearly always of fine texture and only slightly micaceous. Even this part of the Permian in places contains some gypsum and salt. The limestones are mostly thin and in many cases bituminous and fine-grained, and some are oolitic. There are also dolomites, which are mostly also thin, and may show bituminous material. Nearly all water found in the Permian of the plains is salt or even briny. Some of the shales and marls in the Permian of the Plains have a peculiar delicate dove-blue color.

The Pennsylvanian Formations

The Pennsylvanian underlies extensive parts of Texas. It is exposed in the north central part of the state which may be roughly encompassed by a periphery extended from Montague to San Saba, from there to near Paint Rock, and then to Henrietta. West from this belt it dips under the Permian and has been entered in deep borings at San Angelo and at Spur. West of the state it again comes up to the surface east of the Front Range in New Mexico as well as in Texas, so that it no doubt underlies, at depths from 3000 to 5000 feet, the entire Panhandle and the Llano Estacado. The Pennsylvanian no doubt underlies the Comanchean Plateau from the latitude of San Angelo to the Mexican Border. Eastward from the line joining San Saba and Montague, the Pennsylvanian underlies the Comanchean at increasing depths to quite near the Balcones Escarpment. Whether it also underlies the Coastal Plain east of the Balcones Escarpment can not yet be regarded as proved, though it seems likely. In this direction it is covered first by the Cretaceous and farther out east and south by the Tertiary and may be looked for at depths from 5000 to 6000 feet or still deeper near the coast. West of the Pecos, the Pennsylvanian no doubt underlies most of the region, though at greatly varying depths. It outcrops in the Franklin, the Hueco, the Chinati and in other mountains and in the Marathon and the Solitario uplifts and is elsewhere mostly covered by later deposits, in places at depths of evidently many thousand feet.

The formations making the Pennsylvanian series measure in different parts of the state from nothing, where eroded away, to five or six thousand feet, as in the Marathon region. They consist of shales, sandstones, and limestones, in part in frequent alternations. The shales and clays are mostly entirely free from calcareous material, by which fact they can usually be recognized from Cretaceous clays. In the lower part of the series they are mostly dark or bluish gray. Higher up they are partly reddish, brownish, or purplish, which colors alternate with gray, bluish and dark colors. In the central part of the state they contain some small seams of coal. Many of the clays are fine-textured, and show slickensides or jointing. The darker shales generally contain miscroscopic foraminifera, and they seldom fail to contain minute black shreds of carbonaceous material. They also frequently contain concretions ("boulders") of clay-iron-stone or even continuous strata of this nature. The sandstones range into occasional fine conglomerates. They may be open-textured or compactly cemented with lime. Some are petroliferous, as at Electra, Moran, and Strawn. As a rule the sands are moderately fine and the grains angular. Most water found in Pennsylvanian sands is salty. The limestones present great variations. In thickness they range from a few inches to hundreds of feet. They are in rare cases dolomitic. Generally they consist to a considerable extent of organic fragments. In most of them may be found Fusulinas and especially segments of crinoid stems, which can quite readily be found and noted. These are common also in many shales and clays of the Pennsylvanian. The color is varied but mostly gray. Some are sandy, some shaly. In the thickest limestones, chert and flint are common at some horizons.

THE BEND FORMATION

This is the deep formation which is oil-bearing in the Ranger field. It is possibly of Pottsville age, and clearly lies near the middle of what is generally called the Carboniferous strata. It is known to outcrop in McCulloch, San Saba, Mason, Gillespie, Blanco, and Burnet counties, and underlies the later Carboniferous to the north of this region and no doubt in many places underlies the Comanchean and possibly also later Carboniferous strata west and south of the Central Mineral Region. It is likely enough that the Bend is to be correlated with the Dimple formation in Brewster County, which is Pennsylvanian in age.

The Bend formation consists mostly of limestone but with this is also some shale. One of the shaly members occurs in the limestone. The other forms the basal member of the formation. Part of the limestone and nearly all of the shale is dark, almost black. Much of this limestone can be told from later limestones in the Pennsylvanian by its somewhat more developed crystallization. When observed in thin sections this crystallization is seen to give the rock a blotched or streaked appearance, with irregularly shaped and distributed areas of crystalline and granular tracts. The largest microscopic calcite crystals have a decided tendency to radiate from what appears to be microscopic organic centers. Thin microscopic sections of this rock are rarely entirely free from spicules of sponges and in some layers these are present in profusion. The formation also contains some black chert. Some calcareous layers in the upper shale are filled with sponge spicules and are quite siliceous. To some extent the shales in this formation may be recognized by not making as much fine mud under the drill as is the case with most of the shales of later Pennsylvanian deposits.

THE MISSISSIPPIAN, THE DEVONIAN, AND THE SILURIAN FORMATIONS

Rocks of these ages are of very little importance to drillers in Texas, unless it should be found that the Bend is of late Mississippian age, which can not yet be regarded as demonstrated. The Fussulman limestone in the Franklin Mountains, and the upper part of the Maravillas chert in the Marathon uplift probably are of Silurian age, and the Caballos novaculite in Brewster County, a conspicuous white flint, is probably Devonian.

The Ordovician Formations

In the central part of the state the Ordovician is represented by the upper part of the Ellenburger limestone which is a hard, fine-grained, and compact white rock that changes downward into a somewhat more coarse-grained but still hard and yellowish dolomite, containing some oolitic layers and some white chert. The lower part of the Ellenburger belongs to the Cambrian. The two make one continuous formation, a thousand feet thick, without any interbedded shales or clays. It has been entered by a deep boring at Myra, in Cooke County, where it comes up to within some 2200 feet of the surface, and has also been encountered in some borings in a triangular area roughly outlined by a line connecting Parker, Lampasas, and McCulloch counties, where this formation underlies the Bend, which is oil-bearing. It outcrops in McCulloch, San Saba, Mason, Llano, Burnet and Gillespie counties, and no doubt will be found underlying later rocks in the region adjacent to these counties. In Brewster County rocks of this age have been found in the Marathon uplift and contain dark flint and chert and consist of thin-bedded, dark, bituminous limestones and shale. The El Paso limestone, also of this age, is a dolomite 1000 feet thick on the southwest of the Hueco Mountains, underlying the Hueco limestone in that region. The Montoya limestone near El Paso is also Ordovician.

The Cambrian Formations

Formations of Cambrian age occur in San Saba, Mason, Llano, Burnet, Gillespie and adjacent counties, and have been drilled into for water or for oil in these and in some adjacent counties. Much of the Cambrian consists of gray or red sandstone. Some of this is mixed with lime and glauconite. The upper part of the Cambrian is a hard, dolomitic limestone, the Ellenburger limestone described above. This measures several hundred feet in thickness. West of the Pecos the Cambrian is all sandstone. It is known as the Van Horn, the Bliss, and the Brewster sandstones.

Archean and Igneous Rocks

Rocks of Archean ages are mostly granite, gneiss and schist, and they occur in Llano, Burnet, Gillespie, and Blanco counties. They have been entered under overlying later rock in some borings in these and adjacent counties. The schists can usually be known by their abundant mica and the granite by its pink feldspar. Schistose rocks have been reached in some deep borings at Georgetown and near San Antonio. Chloritic rocks, and dark basaltic rocks occur in Kinney, Uvalde, Medina, Travis and Williamson counties, and may exist also in Hays, Bexar, and Guadalupe counties. These are of igneous origin. The former may be known by its dark green color and by its softness, the latter by its dark color, crystalline texture, and extreme toughness and hardness. West of the Pecos, lavas and basalts cover much of the land. They are underlain in many places by volcanic tuffs, and sands in which drilling operations are often successfully made for water, as in Jeff Davis, Presidio and Brewster counties.

TABLES FOR IDENTIFICATION OF SOME MINERALS AND ROCKS

Owing to the different chemical and physical properties of minerals and of rocks they may usually be recognized by characteristics that become evident on close inspection, or which appear from their reactions to some simple tests to which they may be submitted. Some of these tests were known to the ancients and are practiced in various trades today. Some of the processes involved are fundamental to great industries. Non-magnetic iron ores change to iron when smelted, and then become magnetic. Carbon dioxide gas is evolved from carbonates, such as calcite or carbonate of soda, when acted on by hydrochloric acid. This is the way "soda water" is made. It is the same gas we see forming when a fragment of limestone effervesces in the acid. Lime is burned from limestone and it slacks in water. So does a small fragment of the same rock, when heated to redness and then placed in a drop of water.

By taking advantage of these and other well known processes, trying first one and then another, it is possible to correctly identify all of the more common sedimentary rocks. They involve the fundamental rudiments of determinative mineralogy. To aid the beginner some tables have here been prepared, showing characteristics of different materials as they appear to the unaided eye or under a common magnifying glass, and also some characteristic reactions which minerals and rocks show when subjected to a few tests. These examinations and tests are as follows:

1..Observation of general appearance.
2..Examination of texture.
3..Observation of color.
4..Observation of streak.
5..Test for hardness.
6..Acid test.
7..Test for fumes.
8..Fire test.

To make the required observations it is not necessary to have much apparatus. What little is needed can be obtained at very small expense and effort. The following will suffice:

1..A small magnifying glass, such as a linen tester, which can be bought in any jewelry store, or from any dealer in optical goods.
2..An acid bottle filled with a twenty per cent solution of hydrochloric acid. The bottle should have a glass stopper.
3..A pocket knife.
4..A "tin" spoon, or a thin sheet of iron, as from a "tin" can.
5..A piece of broken window glass.
6..A small horseshoe magnet.
7..Pieces of broken porcelain or chinaware.

In case of most materials it will not be necessary to make all of the observations and tests described. One or another may be made first, according to the judgment of the observer. In every case, when a conclusion has been reached, the brief description of the identified rock or mineral found in this text should be consulted before the identification is recorded.

A practice has recently been resorted to by inexperienced drillers who record some materials in the log merely as "rock.' This gives no clue at all to the nature of the material so described, except perhaps that it is harder than the materials above and below it. The fact is that all formations consist of rock: sand and clay are rock, as well as sandstone, limestone or granite. Evidently the term is used when the log-maker is unable to tell, or too hurried to note whether the "rock" is limestone or sandstone. Sometimes inability to make the necessary distinction is quite excusable as in case of a cemented sandstone of fine texture. "Hard rock, undetermined," would be a more proper record in such a case. A sandstone cemented with calcareous material will effervesce in acid, but if a few fragments be crushed and treated with a sufficient quantity of acid until effervescence ceases, the quartz grains of the sand will remain and can be seen through a magnifying glass.

TABLE 1. GENERAL APPEARANCE UNDER A MAGNIFYING GLASS

For best results the sample should be washed clean of all fine material. This can be done in the hollow of the hand, where examination can be made of the sample while in clear water. This examination should be followed by other tests, according to the judgment of the observer. Cuttings of dolomite and of dolomitic limestone are readily mistaken for sand, especially when the cuttings equal sand grains in size. They differ from most sands in having sharp angles. Very compact anhydrite, on account of its translucency and mode of fracture, which may resemble that of chert, has been mistaken for the latter rock. The characteristic of clay, of marl, and of most shales is that they are difficult to wash. They make the water turbid, even after repeated rubbing and washing. The characterizations in the table below refer to the cuttings as they have been broken up by the drill.

Loose rounded grains	Rounded grains adhering together	Fragments all with rather rough surfaces, and angular.	Fragments with flat, shiny, glittering, and crystalline surfaces and sharp angles	Fragments with very sharp angles, translucent on edges and with smooth and more or less evenly curving surfaces.
Quartz sand Oolitic limestone, or Glauconitic sand	Sandstone Quartzite Oolitic limestone Oolitic chert Oolitic flint, or Glauconitic sandstone	Shale, marl, slate (generally in flat fragments) Limestone Dolomite Anhydrite	Gypsum Anhydrite Calcite Dolomite Crystals of pyrite Travertine Crystalline limestone Fe.dspar Quartz sand with secondarily crystallized grains.	Chert, or Flint Fine-textured dolomite Anhydrite, or Limestone

TABLE 2. EXAMINATION OF TEXTURE

Texture has reference to the fineness and coarseness of grain of a rock. We also speak of silky and laminated or bladed texture or grain. Where there is total absence of structure the material has a waxy lustre, and is said to be compact in texture. This has, of course, reference only to appearance to the unaided eye, or under a common magnifying glass. When seen in thin section under a microscope, few, if any, sedimentary rocks are entirely homogeneous, so as to be properly called compact. From the compact texture we have all gradations of fine and coarse texture in limestone, dolomite, and alabaster (anhydrite and gypsum). The classification of sedimentary rocks as to texture is a feature of much importance. Characterizations given in the table below refer to the parts of which the rock consists before being broken, not to the form of the cuttings as they are shaped by the action of the drill.

Elements of rock consist of rounded or angular grains or pebbles.	Elements of rock consist of angular grains or angular pebbles, not crystals.	Elements of rock are almost too small to appear as distinct grains with the aid of a common magnifying glass.	Elements of rock not distinguishable with the aid of a common magnifying glass.
Sand Gravel, conglomerate Oolitic limestone Oolitic chert	Arkose Breccia	Silt Very fine sand Silty shale	Clay Shale Slate Marl Many limestones Dolomites Alabaster Anhydrite rock etc.

TABLE 3. OBSERVATION OF COLOR

Color is really one of the most uncertain characters for identifying rocks and minerals. Almost any rock may have any color. Many underground formations maintain the same color for long distances. Others may change color in a short distance. Limestone is generally light bluish gray, light yellowish gray, or just neutral gray. The same may be said of sandstone. But sandstone is also often yellow, brown, or red. Clay, shale and slate vary more in color than any other type of rock. Black color is due to either the presence of bitumnious and carbonaceous material, or to the presence of such minerals as pyrite and wad, finely disseminated. Only a few colors are mentioned below, and those mentioned are such as are fairly constant.

Color black.	Brass color or silvery color.	Color green.	Color brown, red or yellow.
Bituminous or carbonaceous rock of any kind. Pyritiferous and manganiferous rock of any kind.	Pyrite or Marcasite.	Glauconitic rock Serpentine	Hematite. Limonite.

TABLE 4. OBSERVATION OF STREAK

Streak is the color of rocks and minerals when finely powdered. This is much more characteristic than the color of the mineral or rock, when not powdered. A ready way to determine the streak is to rub the fragment under investigation on a white hone or on the rough edge of a broken piece of porcelain or chinaware, and to notice the color of the "streak" thus made.

Streak colorless, white or nearly so.	Streak red.	Streak yellow.	Streak greenish b.ack.	Streak pale green.
Most siliceous and calcareous rocks of almost whatever color when not powdered.	Hematite	Limonite	Pyrite Marcasite	Glauconjte Serpentine Hornblende.

TABLE 5. TEST FOR HARDNESS

Hardness is to be distinguished from toughness. Fine textured anhydrite and some clay-iron-stone is hard to drill on account of the toughness of these materials, but these rocks have no great hardness. Hardness is the quality enabling one substance to penetrate, cut, or scratch another substance. A hard rock, if it is brittle, may be easier to drill than a softer rock. The tests for hardness as well as most other tests, require much practice and good judgment. Most determinations can be made with nothing more than the point of a pocket knife. With the exception of a few minerals, among which are hematite and limonite, hardness is a quite constant characteristic for each kind of rock and mineral. The hardness test is relatively quite decisive.

Soft enough to be crushed under the thumb nail.	Soft enough to be scratched with a knife blade. Too soft to scratch when pressed against glass.	Hard enough to scratch glass, when pressed against it with a piece of hard wood.
Clay, most shales, chalk, gypsum, anhydrite, talc.	Limestone, Dolomite Clay-iron-stone Anhydrite, Chalk, Barite Feldspar (some kinds)	Sandstone, flint, chert, quartzite, quartz, pyrite, feldspar (some kinds).

TABLE 6. ACID TEST

Hydrochloric acid attacks all carbonates, causing effervescence, or bubbling. A drop of the acid may be let fall on the sample. A better way is to place a few drops of acid on a clean flat glass or on the bottom of a cup or of a saucer, turned upside down. Then select clean fragments of the particular material to be tested and place them in the acid on the glass or cup and watch results carefully, under a magnifying glass, if necessary. In powdered condition, the material tested effervesces most rapidly usually producing a froth. The strength of the acid generally used is twenty per cent. This should be kept in a small glass-stoppered bottle.

Examine in twenty per cent hydrochloric acid by placing a small clean fragment in a few drops of the liquid.

Effervescence brisk.	Effervescence slow.	Effervescence very slow, to be seen best only when material is finely crushed or powdered.	Effervescence lacking.
Caliche Limestone, Chalk, and possibly Marl, Calcareous sandstone.	Dolomite, possibly calcareous clay, marl or sandstone Clay, Marl, or Sandstone	Clay-iron-stone, possibly Marl, or Calcareous shale or clay	Sandstone (pure) Quartzite Quartz Chert Feldspar Flint Gypsum Anhydrite Clays and Shales, free from calcareous material Igneous rocks Coal Lignite Asphalt Barite.

TABLE 7. TEST FOR FUMES

This test can, with some materials, be made by heating to a point short of redness on a sheet of iron ("tin") or in a spoon (or shovel) over the forge. Better results are obtained if a glass tube or brass or iron tube is used. This must be closed at its lower end. The material is then introduced dry and shaken down to the closed end, after which the closed end is heated. Moisture will come first, and on cooling, will deposit drops on the inner side of the tube. Oil and asphalt will follow next, and can be recognized by their odor. Sulphur, present in pyrite, gypsum and anhydrite, follows with the bitumens or at a little higher heat. This is also usually easily recognized by the sulphur or "rotten egg" odor. In case of gypsum and anhydrite, if no odor is detected, the presence of sulphur fumes may be ascertained by their blackening a bright silver coin placed against the open end of the tube. Ammonia fumes are present in many shales, clays, and limestones, and may be recognized by their peculiar pungent odor. The ammonia fumes come at a temperature just below first redness.

Odor like rotten eggs, or like sulphur.	Odor like burning coal	Odor like burning oil	Odor like ammonia
Anhydrite Gypsum Barite Pyrite Marcasite.	Lignite Coal	Bituminous rock Asphalt	Many bituminous shales

TABLE 8. FIRE TEST

When rocks are heated to redness while exposed to the air, some unedrgo changes by which they may be recognized. Some can be known by the fact that they withstand the effects of heat to a greater extent than others. High heat drives away the carbon from carbonates and the sulphur from sulphates and sulphides, thus changing their appearance and physical character. The fire test is one of the earliest and surest known. It is best performed with a blow pipe, but can also be performed in other ways. The heat nearest to a derrick is that of the forge, and the following observations are designed to be made on cuttings heated on a strip of sheet iron or "tin" in a forge. Only a small quantity of washed cuttings should be used, and a magnet should be used to pick from these, before heating, any particles of iron, steel, or rusty scale, which have come into the sample from the drill or from the tubing in the boring.

Material will slack in a little water after heating to redness.	Material turns white or at least lighter in fire, and becomes powdery, but will not slack in water after heating to redness.	Material remains unchanged, if not fused, after heating to redness.	Material is attracted by a magnet after heating to redness for a few minutes	Material glows for a moment, or burns with a flame.
Limestone Dolomite.	Gypsum and Anhydrite	Flint Chert Sandstone Quartzite or Shale, possibly an Igneous rock	Pyrite Marcasite Clay-iron-stone Hematite Limonite	Coal Lignite Asphalt, if it fuses.

NOTICE

Readers of this text, interested in the geology of Texas, will find it advantageous to have at hand for reference Bulletin 44 of the University of Texas. This has been prepared by the Bureau of Economic Geology, and is a review of the geology of the state as far as it has been made out to the present time. It contains maps and sections for ready reference and clear presentation of the known surficial distribution and the thickness and nature of the formations described only very briefly in this text. Bulletin 44 will be mailed promptly on the receipt of the price ($1.00).